Appendix C: Baseline beneficial use status of the Malheur River Basin

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TABLE OF CONTENTS

INTRODUCTION

This report describes the ecological conditions of wadeable, perennial streams in Oregon's Malheur River Basin, and relates indicators of chemical and physical conditions to the conditions of the biological communities. Results are based on surveys of 24 randomly selected streams throughout the Malheur Basin in August 2006. Streams were sampled for water chemistry, physical habitat, and macroinvertebrate assemblages.

A randomized subsample of locations within the basin was used to accurately represent conditions across the entire basin. A direct assessment of ecological stream conditions was made, in addition to the traditional chemical and physical indicators water quality indicators. Biological assemblages are useful for understanding watershed health because they integrate the effects of the chemical and physical properties of the stream over time. A measure of biological conditions provides a more complete picture of overall stream conditions than a water sample alone.

The goal of this report is to present an unbiased account of the current status of the ecological conditions of wadeable, perennial streams throughout the Malheur River basin. This information should be useful in setting future priorities for stream resource management in the basin.

METHODS

Sampling Design

We used a probabilistic sampling design to select survey stream segments throughout the Malheur basin. This means a subsample of stream sites are selected at random to represent the population of streams in the basin (in this case, all perennial and wadeable stream kilometers). With probabilistic sampling designs, each sampling site has a known probability of being selected, and thus represents a portion of the total stream population. A detailed description of this type of study design can be found in Stoddard et al. (2005).

The random sites surveyed are shown in Figure 1. Two classes of streams were excluded from the target population. Intermittent streams were not surveyed. Non-wadeable streams (large streams and rivers) were also excluded.

Extent of Resource Assessed

The total length of targeted stream kilometers in the Malheur River basin was 6,458 km. Our surveys represented 4,779 stream km, or 74% of the targeted population. We were unable to assess approximately 26% of the perennial, wadeable streams in the basin—due to access denials from private land owners. Thus, the results presented here are more heavily weighted towards conditions on publicly owned lands.

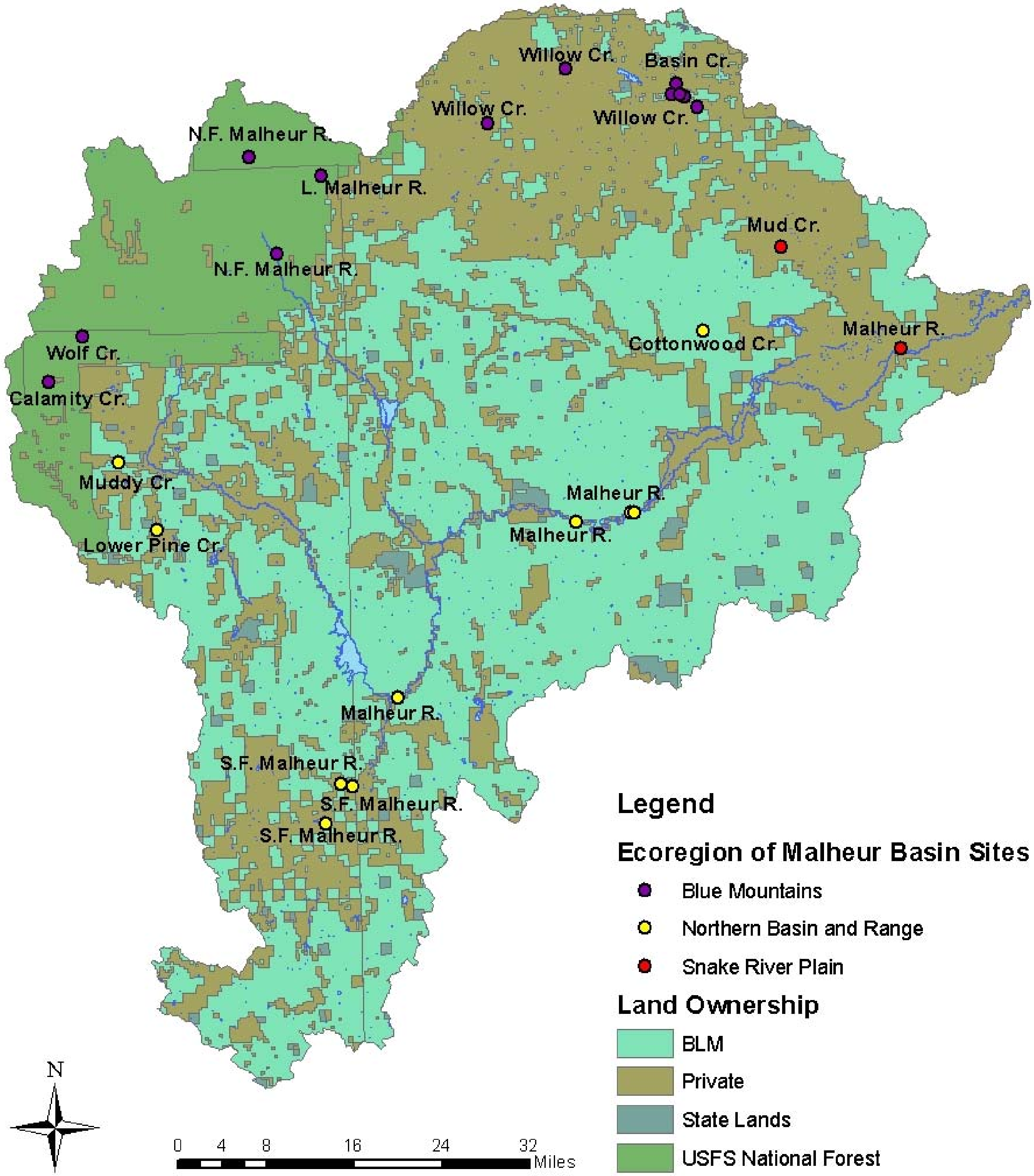

Figure 1. Malheur Basin TMDL study area. Random sampling locations are shown with different colored dots, according to which Level III ecoregion the site resides.

Indicators of Ecological Condition

We collected information on a single biological assemblage, macroinvertebrates (insects, clams, snails, etc.). Without information on the aquatic vertebrate and algal assemblages it is likely that all the potential risks to ecological integrity of the Malheur basin have not been identified. However, macroinvertebrate assemblages are useful indicators of ecological health. Macroinvertebrates occupy a central role in food chains and the ecosystem. They are easy to collect, are relatively inexpensive to process and analyze, and respond to a variety of stressors. Macroinvertebrates are the most commonly used aquatic assemblage for assessing stream biological integrity. For a thorough examination of the role of macroinvertebrates in assessing biological integrity, see Rosenberg and Resh (1993) and Wright et. al (2000).

Samples were collected from erosional (riffle) habitats. Samples were collected using a D-frame kicknet, with a mesh size of 500 µm. Eight randomly collected 1-ft^2 kicks, one from each of eight different riffle habitats, were composited into a single sample. Samples were randomly sub-sampled to 500 individuals in the laboratory at 10x magnification. For full details of macroinvertebrate sampling procedures see ODEQ (2004a).

Biological condition

We used a “Taxa Loss” model to assess macroinvertebrate integrity. This model, the PREDictive Assessment Tool for Oregon (PREDATOR), uses multivariate statistics to predict the expected macroinvertebrates that would be found at a random site if the site were in reference conditions (least impaired). The number of expected taxa (E) was compared to the observed taxa (O) at reference sites with similar environmental characteristics (elevation, stream size, gradient, etc.). The ratio of observed to expected taxa (O/E) is a measure of the loss of taxa commonly observed at reference sites. An O/E < 1.0 means that fewer taxa were observed than were expected, while an O/E >1.0 means more taxa were observed than were expected (Hubler 2008).

Two separate PREDATOR models were used to assess the random sites in this study. The first model was built with reference sites spanning the Klamath Mountains, Cascades, East Cascades, Columbia Plateau, and Blue Mountains Level III ecoregions. Any random site in the Malheur basin that was in the Blue Mountains ecoregion was assessed by this model. This model was built with many reference sites and performs well. Random sites in the Malheur basin that were located in the Northern Basin and Range ecoregion were assessed with a model built from only 9 reference sites. With only 9 reference sites, it was not possible to create a predictive model in this region. Instead, a null model was used to make assessments. This model has a much lower level of accuracy than the predictive model used to assess sites in the Blue Mountains portion of the Malheur basin. (See Hubler 2008 for details of model performance.)

Stressor identification

Weighted averaging stressor identification models were used to assess stress to the biological assemblage related to temperature and fine sediments (Huff et al 2006). These models detect shifts in the overall preferences of the macroinvertebrate assemblages for summer maximum temperature and percent fine sediment. Step one involves calculating the optimum temperature and fine sediment values for an individual macroinvertebrate taxon, by weighting the environmental variable by the taxon’s abundance, then summing these values across all locations where the taxon was observed. Step two is to infer temperature and fine sediment stress (as ^{o}C and % fines, respectively), the optimum for each taxon was weighted by its abundance, then summed across all observed taxa in the sample.

Indicators of Stress (Water Quality & Physical Habitat)

Human activities throughout a watershed may alter the conditions within a stream beyond what is naturally observed for these variables. Because the biological communities have adapted to these natural conditions, alteration of the chemical and physical habitat characteristics may depress the ecological condition of streams.

Water Quality
All water chemistry samples were collected as a one-time grab sample from the bottom of the stream reach. Chemistry samples were collected prior to collection of other samples, to avoid altering the chemistry results. See ODEQ (2004a) for both field methods and laboratory methods for grab water chemistry samples.

Parameters measured in the field were dissolved oxygen, pH, temperature, conductivity, and turbidity. Total suspended solids, alkalinity, ammonia, nitrate/nitrite, total Kjeldahl nitrogen, total phosphorus, and total organic carbon were measured in the Lab.

Physical Habitat
Instream and riparian habitat was surveyed over a stream reach of 40-times the wetted width. The habitat assessment included both quantitative and qualitative measures of instream and riparian habitat characteristics. Detailed descriptions of field methods for bedded sediment composition, width and bankfull width, and densitometer measurements are listed in Peck et al. (2006) and habitat metric calculations are shown in Kaufmann et al. (1999).

Buffer width and height were measured using a laser range finder. Several height measurements were taken and then averaged. In open country, the buffer width was the extent of riparian species. In forested areas it was generally the extent of the flood plain that contained woody species. Widths and heights were generally measured in the vicinity of each of the shade measurement locations for each station.

A solar pathfinder was used to make measurements of shade over the stream. The solar pathfinder was placed in the center of the stream channel and oriented in alignment with a north compass direction. Percent effective shade was measured along the curve for July, which is the month with the highest expected maximum temperatures. Measurements were made at a central "x" spot and then at two locations approximately 50 meters upstream and downstream. These three measures were then averaged into a single measure of percent cover

Percent coniferous and deciduous measurements were based on visual estimation of the riparian buffer.

Correlations among biological indices and indicators of stress

Correlations analyses were performed to look for relationships between biological indices and potential indicators of stress. Indicators of stress included water chemistry and physical habitat variables. Each of these indicators have a natural range of conditions across the landscape, however, beyond a certain threshold each of the variables could potentially cause stress to the biological assemblage.

Water chemistry and physical habitat data were transformed, where necessary to improve normality, and Pearson's correlation coefficients (r) were calculated. Relationships between a biological index and an indicator of stress were considered strong when correlation coefficients (r) ≥ 0.50, while coefficients $0.30 \leq (r) < 0.50$ were considered to show a moderate relationship.

Setting Expectations: The Reference Condition Approach

Selecting Reference Sites:

In order to make an assessment of stream condition, one must define what constitutes acceptable conditions for each indicator. The reference condition approach has been widely used to identify least-disturbed conditions and set expected values or benchmarks for specific parameters, especially for parameters without clearly defined standards or criteria (Stoddard et. al 2006). Least-disturbed conditions represent "the best of what's left" for any given region. In some parts of Oregon much of the landscape is relatively undisturbed, while in other regions the landscape has been altered more extensively by human activities. Expectations of what constitutes a natural range for an indicator of stress were based on regional reference sites within Level III Ecoregions (Omernik 2004). Ecoregions combine elements of geology, climate, elevation, and vegetative communities. Similar physiographic and biological characteristics make Level III Ecoregion a useful scale for deriving benchmarks based on reference condition.

ODEQ methods screen prospective reference sites at the local (reach) and watershed scales for the lowest levels of human activities (Drake 2004).

A total of 36 reference sites (Table 1) were used to establish indicator benchmarks. We aggregated some Level III ecoregions due to the low number of available reference and the basic similarity of the aggregated ecoregions (they all belong to the same Level II ecoregion).

Table 1. Level 3 Ecoregions in the Malheur River basin and the number of sites used to establish reference benchmarks.

<table>
<tr><th>Ecoregion</th><th>Oregon</th><th>Washington</th><th>Idaho</th><th>Total</th></tr>
<tr><td>Blue Mountains</td><td>19</td><td>1</td><td>1</td><td>21</td></tr>
<tr><td>Columbia Plateau</td><td>0</td><td>4</td><td>0</td><td rowspan="3">15</td></tr>
<tr><td>Northern Basin & Range</td><td>9</td><td>0</td><td>2</td></tr>
<tr><td>Snake River Plains</td><td>0</td><td>0</td><td>0</td></tr>
</table>

Setting Assessment Benchmarks

Oregon and other states set water quality standards and criteria to protect the beneficial uses of streams and rivers. For this assessment we used Oregon's water quality standards to evaluate conditions for those indicators with established numeric standards (dissolved oxygen, temperature, and pH; Appendix A). When the standard was met, the water quality condition was considered "least disturbed", and when the standard was not met, the water quality was considered "most disturbed". For water quality and physical habitat indicators without a standard, we used reference site values to establish three classes of stream condition. We were only able to use reference benchmarks for those parameters that were also assessed in the Statewide Assessment of Wadeable Streams (ODEQ 2007, Appendix A). Where increasing indicator values were associated with a declining biological indicator response, the upper 75th and 95th percentiles of reference values were used to distinguish condition classes. Where decreasing indicator values were associated with a declining biological indicator response, the lower 5th and 25th percentiles of reference values were used (Table2).

PREDATOR taxa loss benchmarks and stressor identification benchmarks were based on the 10th and 25th percentiles of reference sites stressor scores (Table 2). For both types of models, the benchmarks applied to an individual site in the Malheur basin varied by which Level III ecoregion the site was located.

Table 2. Benchmarks used for determining condition classes for indicators of biological condition.

Biological Indicator	Least Disturbed	Moderately disturbed	Most disturbed
PREDATOR Taxa Loss (O/E)			
Blue Mountains	≥ 0.90	0.90 > O/E ≥ 0.75	> 0.75
Northern Basin and Range, Snake River Plains	≥ 0.75	0.75 > O/E ≥ 0.50	> 0.50
Temperature Stress			
Blue Mountains	≤ 17.1	17.1 < TS ≤ 18.3	> 18.3
Northern Basin and Range, Snake River Plains	≤ 20.7	20.7 < TS ≤ 22.0	> 22.0
Fine Sediment Stress			
Blue Mountains	≤ 20.8	20.8 < TS ≤ 22.0	> 22.0
Northern Basin and Range, Snake River Plains	≤ 17	17 < TS ≤ 33	> 33

RESULTS

Correlations to Biological Indicators

Results of the correlations among indicators of stress to the biological indicators are shown in Table 3. (Correlations among each of the indicators of stress are shown in Appendix B.) Not surprisingly, as measures of biological temperature and fine sediment stress increased, overall biological condition (PREDATOR taxa loss) decreased. Fine sediment stress showed a stronger relationship (r = -0.51) to biological condition than did temperature stress (-0.39). Biological inferences of temperature stress and fine sediment stress were strongly correlated (0.66).

Biological condition
Nutrients and suspended sediments were strongly negatively correlated with overall biological condition. Moderate negative relationships were observed with several physical chemistry variables. Strong positive relationships to biological condition were observed with indicators of riparian cover. Moderately positive correlations with biological condition were observed for several indicators of riparian cover and dissolved oxygen.

Biological temperature stress
Lower temperature stresses to the macroinvertebrate assemblages were observed for higher amounts of all riparian cover indicators. As temperature stress increased, so did several nutrient, physical chemistry, and larger classes of bedded sediments indicators.

Biological fine sediment stress
Strong negative relationships were observed among the biological measure of fine sediment stress and nearly all measures of riparian condition. Two additional measures of riparian condition, plus stream width showed moderate negative correlations to fine sediment stress. Nearly all water chemistry indicators showed strong or moderate positive correlations with fine sediment stress. Interestingly, none of the habitat indicators of bedded sediment composition were highly correlated to macroinvertebrate inferred fine sediment stress. However, suspended sediments did show a moderate positive relationship to increasing fine sediment stress. Previous probabilistic studies performed by DEQ at various scales (basin, ESU, statewide) and geographic regions have shown total suspended solids and turbidity outside of reference conditions are often associated with poor biological condition. Turbidity values from this study had a strong positive correlation with total phosphorus, total suspended solids, ammonia, organic nitrogen (TKN), and total organic carbon. There was a strong negative correlation between turbidity, buffer width and shade measurements (Appendix B).

Extent of the resource failing to meet reference expectations

Understanding the relative importance of an indicator as a stressor to the biological community can help resource managers determine which environmental factors pose the greatest risk to maintaining healthy aquatic communities. One way to do this is to identify the relative extent of stream resource in "most disturbed" condition for the assessed variables. With this approach it is possible to identify those indicators with the most widespread poor condition throughout the Malheur basin.

The indicators showing the greatest extent of assessed stream kilometers in most disturbed conditions were temperature stress (92%), total phosphorus (79%), and conductivity (75%) (Figure 3). Other indicators showing > 50% of stream kilometers in most disturbed condition included canopy cover (67%), turbidity (62%), and fine sediment stress (54%). The indicator with the lowest extent of wadeable, perennial stream miles in most disturbed condition was % fines (29%).

The actual percent of stream kilometers across the Malheur River basin listed in "most disturbed" condition for any given parameter is likely under-represented in this report. The percent of stream kilometers that were not assessed for all indicators was 26%. Most of these stream kilometers were not assessed due to private landowners restricting access for the surveys, thus results are more reflective of conditions on publicly owned lands.

Table 3. Correlations among biological indicators and water quality and physical habitat indicators for the Malheur River Basin. Pearson's correlation coefficients (r) ≥ 0.50 are displayed in red, and 0.30 ≤ (r) < 0.50 are displayed in blue. Positive and negative correlations are denoted by the sign,

Indicator Type	PREDATOR (Taxa Loss)	Temperature Stress	Fine Sediment Stress
Biological Indicators			
PREDATOR (Taxa loss)	--	**-0.39**	**-0.51**
Temperature stress	**-0.39**	--	**0.66**
Fine sediment stress	**-0.51**	**0.66**	--
Stream size			
Width	0.02	0.21	**-0.38**
Bankfull width	-0.02	**0.31**	-0.28
Riparian Cover			
Buffer height	**0.37**	**-0.76**	**-0.75**
Buffer width	**0.59**	**-0.43**	**-0.56**
% Coniferous riparian	**0.44**	**-0.60**	**-0.71**
% Deciduous riparian	**0.34**	**-0.38**	**-0.33**
Solar pathfinder (mean)	**0.58**	**-0.70**	**-0.63**
Center densiometer (mean)	**0.53**	**-0.79**	**-0.53**
Bank densiometer (mean)	**0.48**	**-0.61**	**-0.31**
Bedded sediments			
% Fines	0.03	-0.25	0.18
% Gravel	0.27	**-0.36**	-0.21
% Cobble	-0.14	**0.32**	-0.17
% Boulder	-0.01	0.23	0.16
% Big substrate	-0.14	**0.39**	-0.10
Suspended Sediments			
Turbidity	**-0.56**	0.27	**0.35**
Total suspended solids	**-0.51**	0.28	**0.47**
Physical Chemistry			
Dissolved oxygen	**0.36**	0.23	-0.21
Dissolved oxygen (saturation)	**0.34**	0.29	-0.10
pH	-0.06	**0.31**	0.18
Temperature (grab)	**-0.40**	**0.66**	**0.63**
Conductivity	**-0.36**	**0.39**	**0.72**
Alkalinity	**-0.44**	**0.51**	**0.79**
Nutrients			
Ammonia	**-0.40**	**0.40**	**0.47**
Nitrate/Nitrite	-0.13	0.26	0.10
Total Kjeldahl nitrogen	**-0.68**	**0.54**	**0.68**
Total phosphorus	**-0.67**	**0.45**	**0.49**
Total organic carbon	**-0.53**	**0.68**	**0.56**

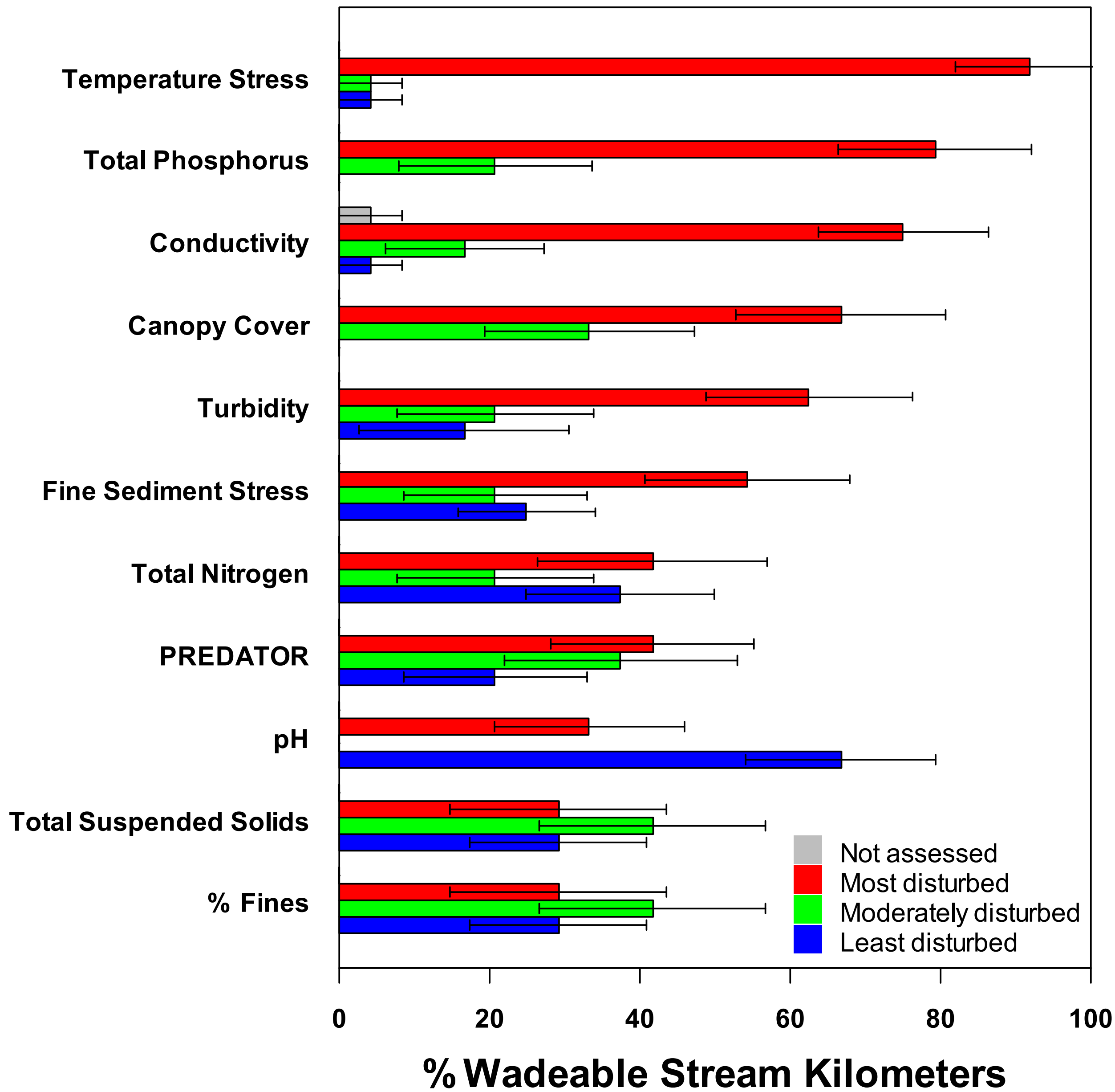

Figure 3. The extent of stream kilometers in the Malheur River basin in each condition class for biological, water chemistry, and physical habitat indicators.

DISCUSSION

In 2006, we collected data from 24 randomly selected sites across the Malheur basin to assess the ecological condition of perennial, wadeable streams. We found 42% of targeted stream kilometers were in most disturbed condition for PREDATOR taxa loss. Twelve out of the 24 random sites were located in the Northern Basin and Range ecoregion, and thus were scored with the less reliable PREDATOR model. It is possible that the extent of stream kilometers in most disturbed condition for PREDATOR taxa loss are underestimated due to poor predictions of expected taxa. Nearly all targeted stream kilometers (91%) were in most disturbed condition for temperature stress, while 54% were in most disturbed condition for fine sediment stress. Despite such a high extent of the resource showing higher temperature stress scores than regional reference sites, fine sediment stress scores in the Malheur basin were more highly correlated with overall biological condition (PREDATOR taxa loss).

Biological indices showed strong relationships to riparian condition, nutrients, and physical chemistry indicators. The strongest relationship between biological condition and stressors appears to be related to riparian condition. All riparian indicators of stress showed moderate or strong correlations to biological indices. Riparian cover was shown to be correlated most strongly with nutrients and suspended sediments. Overall, sites with a larger riparian buffer and shade had lower nutrients and suspended sediments.

Report limitations and future recommendations:

This report represents a baseline picture of current conditions of one beneficial use in the Malheur River basin. Unfortunately, only one biological assemblage was available to assess. Different assemblages may be sensitive to different stressors. However, macroinvertebrates occupy a central role in aquatic ecosystems and have proven to be sensitive indicators. Future assessments would benefit by including both periphyton (algae) and aquatic vertebrates.

The sample size used in this study is quite small. Future monitoring in the Malheur Basin would benefit from re-visiting a subset of the sites used in this report, as well as increasing the random sample size to at least 50 sites. This would provide a much more precise measure of the status of biological condition. Additionally, stratification of the survey sites into different populations may be useful (e.g., ownership, land use, stream size, sub-basins, etc.). Also, a major emphasis should be placed on building partnerships with local landowners. Due to lack of access to private lands, this report is more reflective of conditions on public lands. To more accurately report on the beneficial use status across the basin, public and private lands should be sampled more representatively.

Increasing the sample size would allow for the calculation of relative risk to the biology from each of the indicators of stress. In other words, how likely is a site to have poor biological, given a poor chemistry of habitat indicator? With this information, we can identify those stressors that have the greatest impact on biological condition. We have already shown riparian condition to be highly correlated with biological condition, but relative risk would allow us to examine the magnitude of these relationships further.

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Appendix A. Stressor benchmarks.

Table 4. Benchmarks used to determine indicator conditions in wadeable streams. All benchmarks (except for pH and dissolved oxygen) were based on the distribution of indicator values from reference (least disturbed) populations for level III ecoregions in Oregon.

Ecoregion	Coast Range		Willamette Valley + Puget Lowlands		Cascades		East Cascades		Blue Mountains		Klamath Mountains		Columbia Plateau + Northern Basin and Range + Snake River Plains	
	Good	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Poor
Conductivity	< 94	> 160	< 102	> 235	< 58	> 102	< 101	> 195	< 75	> 212	< 174	> 217	< 104	> 136
Turbidity	< 1	> 6	< 5	> 30	< 1	> 2	< 1	> 2	< 1	> 2	< 1	> 3	< 4	> 13
Total Suspended Solids	< 2	> 9	< 4	> 26	< 1	> 66	< 3	> 9	< 2	> 5	< 1	> 10	< 7	> 23
Sulfate	< 6.5	> 10.6	< 2.8	> 9.4	< 2.5	> 17.2	< 1.2	> 3.5	< 3.1	> 5.4	< 4.8	> 23.2	< 2.1	> 4.1
Total Phosphorus	< 0.020	> 0.040	< 0.040	> 0.110	< 0.030	> 0.066	< 0.040	> 0.100	< 0.031	> 0.065	< 0.030	> 0.060	< 0.044	> 0.069
Chloride	< 5.9	> 14.0	< 5.3	> 6.1	< 1.1	> 3.3	< 1.0	> 3.0	< 0.5	> 1.5	< 3.3	> 36.0	< 1.5	> 3.8
Total Nitrogen	< 0.570	> 0.855	< 0.429	> 0.646	< 0.260	> 0.318	< 0.260	> 0.524	< 0.244	> 0.284	< 0.261	> 0.340	< 0.255	> 0.399
pH	WQ standard (statewide): Good = 6.5 - 8.5, Poor = < 6.5 or > 8.5													
Dissolved Oxygen	WQ standard: determined by stream segment (based on fish use and spawning)													
Vegetative Cover	1.00	< 0.73	> 0.96	< 0.95	> 0.95	< 0.68	> 0.91	< 0.77	> 0.8	< 0.05	1.00	< 0.32	> 0.55	0.00
Canopy Cover	> 80	< 30	> 95	< 69	> 71	< 48	> 63	< 37	> 22	< 3	> 71	0	> 47	< 1
Habitat Complexity	> 0.25	< 0.14	> 0.15	< 0.05	> 0.35	< 0.2	> 0.25	< 0.12	> 0.22	< 0.04	> 0.41	< 0.05	> 0.2	< 0.08
Relative Bed Stability	> -0.8	< -1.8	> -0.7	< -0.7	> -0.9	< -1.7	> -1.2	< -1.8	> -1.3	< -1.5	> -0.4	< -0.6	> -2	< -2.9
Large Woody Debris	> 6.7	0.0	> 13.9	< 0.4	> 18	< 4.7	> 8.4	0.0	> 3	0.0	> 0.1	0.0	> 0.4	0.0
Fast Water Habitat	> 35	< 25	> 51	< 23	> 47	< 19	> 64	< 36	> 59	< 27	> 57	< 12	> 55	< 20
Embeddedness	< 51	> 82	< 55	> 78	< 39	> 65	< 63	> 81	< 47	> 70	< 49	> 52	< 63	> 87
All Disturbances	< 0.7	> 1.6	< 1.3	> 2.3	< 0.1	> 0.9	< 0.7	> 1.1	0.0	> 1.8	< 1.2	> 1.4	< 1	> 1.5
Agricultural Disturbances	0.0	> 0	0.0	> 0.4	0.0	> 0	0.0	> 0.7	0.0	> 0.5	0.0	> 0	< 0.7	> 1.5
% Fines	< 7	> 38	< 11	> 18	< 5	> 17	< 13	> 19	< 11	> 22	< 3	> 7	< 23	> 63
% Sand/Fines	< 24	> 45	< 27	> 50	< 13	> 45	< 28	> 44	< 22	> 31	< 7	> 31	< 30	> 71
Slow Water Habitat	< 63	> 75	< 49	> 77	< 51	> 68	< 36	> 64	< 41	> 73	< 41	> 49	< 45	> 80
Residual Pools	> 5	< 2.1	> 9.4	< 4.5	> 4.5	< 1.1	> 4	< 2.5	> 4.6	< 0.6	> 4	< 0.3	> 6.4	< 0.9

Appendix B. Correlations among all field parameters excluding biological indices, which are presented in Table 4. Pearson's correlation coefficients (r) ≥ 0.50 are displayed in red, and 0.30 ≤ (r) < 0.50 are displayed in blue. A positive (r) indicates both variables are positively correlated (as one increases, so does the other). A negative (r) indicates a negative relationship (as one variable increases, the other decreases).

Table 5. Physical chemistry correlations.

	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Conductivity	Alkalinity
Physical chemistry						
Dissolved oxygen		0.97	0.57	0.12	0.00	-0.05
Dissolved oxygen saturation	0.97		0.60	0.29	0.09	0.04
pH	0.57	0.60		0.49	0.43	0.42
Temperature	0.12	0.29	0.49		0.55	0.61
Conductivity	0.00	0.09	0.43	0.55		0.92
Alkalinity	-0.05	0.04	0.42	0.61	0.92	
Nutrients						
Ammonia	-0.27	-0.23	0.09	0.32	0.50	0.58
Nitrate/Nitrite	0.24	0.14	0.04	0.00	0.20	0.26
Total Kjeldahl nitrogen	-0.40	-0.35	0.08	0.35	0.40	0.49
Total phosphorus	-0.30	-0.31	0.12	0.26	0.37	0.52
Total organic carbon	-0.08	-0.06	0.10	0.39	0.29	0.39
Suspended sediments						
Turbidity	-0.43	-0.50	-0.13	-0.09	0.20	0.32
Total suspended solids	-0.32	-0.31	0.11	0.24	0.57	0.52
Stream size						
Width	0.56	0.43	0.05	-0.30	-0.37	-0.33
Bankfull width	0.64	0.53	0.17	-0.15	-0.26	-0.23
Riparian cover						
Buffer height	0.00	-0.08	-0.28	-0.63	-0.42	-0.60
Buffer width	0.22	0.24	-0.23	-0.24	-0.44	-0.63
% Coniferous	0.08	-0.01	-0.18	-0.62	-0.48	-0.61
% Deciduous	-0.06	-0.02	-0.25	-0.09	-0.30	-0.39
Center densiometer (mean)	-0.06	-0.10	-0.27	-0.53	-0.27	-0.40
Bank densiometer (mean)	0.07	0.09	-0.18	-0.28	-0.16	-0.29
Solar pathfinder cover (mean)	0.08	0.06	-0.11	-0.43	-0.36	-0.52
Bedded sediments						
% Boulder	0.03	0.08	0.23	0.17	0.15	0.11
% Cobble	0.19	0.11	-0.03	-0.02	-0.29	-0.20
% Gravel	0.24	0.29	-0.05	0.04	-0.04	-0.15
% Fines	-0.36	-0.35	-0.16	-0.14	0.17	0.18

Table 6. Nutrient correlations.

	Ammonia	Nitrate/Nitrite	Total Kjeldahl nitrogen	Total phosphorus	Total organic carbon
Physical chemistry					
Dissolved oxygen	-0.27	0.24	-0.40	-0.30	-0.08
Dissolved oxygen saturation	-0.23	0.14	-0.35	-0.31	-0.06
pH	-0.09	0.04	-0.08	0.12	0.10
Temperature	0.32	0.00	0.35	0.26	0.39
Conductivity	0.50	0.20	0.40	0.37	0.29
Alkalinity	0.58	0.26	0.49	0.52	0.39
Nutrients					
Ammonia		0.47	0.68	0.64	0.61
Nitrate/Nitrite	0.47		0.14	0.47	0.25
Total Kjeldahl nitrogen	0.68	0.14		0.79	0.85
Total phosphorus	0.64	0.47	0.79		0.70
Total organic carbon	0.61	0.25	0.85	0.70	
Suspended sediments					
Turbidity	0.50	0.35	0.70	0.82	0.54
Total suspended solids	0.57	0.21	0.62	0.69	0.46
Stream size					
Width	-0.05	0.43	-0.03	0.11	0.17
Bankfull width	0.00	0.43	0.02	0.12	0.26
Riparian cover					
Buffer height	-0.30	-0.05	-0.47	-0.40	-0.50
Buffer width	-0.40	-0.15	-0.54	-0.64	-0.52
% Coniferous	-0.43	-0.28	-0.44	-0.44	-0.43
% Deciduous	-0.34	-0.08	-0.44	-0.42	-0.48
Center densiometer (mean)	-0.34	-0.19	-0.64	-0.60	-0.60
Bank densiometer (mean)	-0.24	-0.24	-0.42	-0.58	-0.40
Solar pathfinder cover (mean)	-0.39	-0.16	-0.65	-0.54	-0.54
Bedded sediments					
% Boulder	0.13	-0.20	0.24	0.00	0.49
% Cobble	-0.05	0.17	0.06	0.14	0.28
% Gravel	-0.41	-0.09	-0.49	-0.49	-0.59
% Fines	0.24	0.03	0.08	0.12	-0.19

Table 7. Suspended sediment correlations.

	Turbidity	Total suspended solids
Physical chemistry		
Dissolved oxygen	-0.43	-0.32
Dissolved oxygen saturation	-0.50	-0.31
pH	-0.13	0.11
Temperature	-0.09	0.24
Conductivity	0.20	0.57
Alkalinity	0.32	0.52
Nutrients		
Ammonia	0.50	0.57
Nitrate/Nitrite	0.35	0.21
Total Kjeldahl nitrogen	0.70	0.62
Total phosphorus	0.82	0.69
Total organic carbon	0.54	0.46
Suspended sediments		
Turbidity		0.70
Total suspended solids	0.70	
Stream size		
Width	0.19	-0.16
Bankfull width	0.13	-0.19
Riparian cover		
Buffer height	-0.21	-0.26
Buffer width	-0.67	-0.55
% Coniferous	-0.35	-0.38
% Deciduous	-0.38	-0.43
Center densiometer (mean)	-0.41	-0.26
Bank densiometer (mean)	-0.48	-0.26
Solar pathfinder cover (mean)	-0.51	-0.32
Bedded sediments		
% Boulder	-0.13	-0.12
% Cobble	0.20	0.19
% Gravel	-0.61	-0.40
% Fines	0.19	0.04

Table 8. Stream size correlations.

	Width	Bankfull width
Physical chemistry		
Dissolved oxygen	0.56	0.64
Dissolved oxygen saturation	0.43	0.53
pH	0.05	0.17
Temperature	-0.30	-0.15
Conductivity	-0.37	-0.26
Alkalinity	-0.33	-0.23
Nutrients		
Ammonia	-0.05	0.00
Nitrate/Nitrite	0.43	0.43
Total Kjeldahl nitrogen	-0.03	0.02
Total phosphorus	0.11	0.12
Total organic carbon	0.17	0.26
Suspended sediments		
Turbidity	0.19	0.13
Total suspended solids	-0.16	-0.19
Stream size		
Width		0.95
Bankfull width	0.95	
Riparian cover		
Buffer height	0.16	0.08
Buffer width	0.04	0.04
% Coniferous	0.20	0.12
% Deciduous	-0.18	-0.27
Center densiometer (mean)	-0.28	-0.37
Bank densiometer (mean)	-0.30	-0.34
Solar pathfinder cover (mean)	-0.19	-0.24
Bedded sediments		
% Boulder	-0.16	-0.02
% Cobble	0.42	0.38
% Gravel	-0.15	-0.13
% Fines	-0.23	-0.28

Table 9. Riparian cover correlations.

	Buffer height	Buffer width	% Coniferous	% Deciduous	Center densiometer (mean)	Bank densiometer (mean)	Solar pathfinder cover (mean)
Physical chemistry							
Dissolved oxygen	0.00	0.22	0.08	-0.06	-0.06	0.07	0.08
Dissolved oxygen saturation	-0.08	0.24	-0.01	-0.02	-0.10	0.09	0.06
pH	-0.28	-0.23	-0.18	-0.25	-0.27	-0.18	-0.11
Temperature	-0.63	-0.24	-0.62	-0.09	-0.53	-0.28	-0.43
Conductivity	-0.42	-0.44	-0.48	-0.30	-0.27	-0.16	-0.36
Alkalinity	-0.60	-0.63	-0.61	-0.39	-0.40	-0.29	-0.52
Nutrients							
Ammonia	-0.30	-0.40	-0.43	-0.34	-0.34	-0.24	-0.39
Nitrate/Nitrite	-0.05	-0.15	-0.28	-0.08	-0.19	-0.24	-0.16
Total Kjeldahl nitrogen	-0.47	-0.54	-0.44	-0.44	-0.64	-0.42	-0.65
Total phosphorus	-0.40	-0.64	-0.44	-0.42	-0.60	-0.58	-0.54
Total organic carbon	-0.50	-0.52	-0.43	-0.48	-0.60	-0.40	-0.54
Suspended sediments							
Turbidity	-0.21	-0.67	-0.35	-0.38	-0.41	-0.48	-0.51
Total suspended solids	-0.26	-0.55	-0.38	-0.43	-0.26	-0.26	-0.32
Stream size							
Width	0.16	0.04	0.20	-0.18	-0.28	-0.30	-0.19
Bankfull width	0.08	0.04	0.12	-0.27	-0.37	-0.34	-0.24
Riparian cover							
Buffer height		0.61	0.73	0.52	0.65	0.51	0.64
Buffer width	0.61		0.56	0.59	0.34	0.42	0.58
% Coniferous	0.73	0.56		0.14	0.52	0.44	0.45
% Deciduous	0.52	0.59	0.14		0.40	0.38	0.54
Center densiometer (mean)	0.65	0.34	0.52	0.40		0.84	0.78
Bank densiometer (mean)	0.51	0.42	0.44	0.38	0.84		0.70
Solar pathfinder cover (mean)	0.64	0.58	0.45	0.54	0.78	0.70	
Bedded sediments							
% Boulder	-0.08	-0.04	-0.05	-0.07	-0.08	0.06	0.06
% Cobble	-0.06	-0.19	0.09	-0.32	-0.05	-0.11	-0.12
% Gravel	0.17	0.59	0.17	0.33	0.20	0.31	0.34
% Fines	0.00	-0.10	-0.16	0.19	-0.01	-0.10	-0.10

Table 10. Bedded sediment correlations.

	% Boulder	% Cobble	% Gravel	% Fines
Physical chemistry				
Dissolved oxygen	0.03	0.19	0.24	-0.36
Dissolved oxygen saturation	0.08	0.11	0.29	-0.35
pH	0.23	-0.03	-0.05	-0.16
Temperature	0.17	-0.02	0.04	-0.14
Conductivity	0.15	-0.29	-0.04	0.17
Alkalinity	0.11	-0.20	-0.15	0.18
Nutrients				
Ammonia	0.13	-0.05	-0.41	0.24
Nitrate/Nitrite	-0.20	0.17	-0.09	0.03
Total Kjeldahl nitrogen	0.24	0.06	-0.49	0.08
Total phosphorus	0.00	0.14	-0.49	0.12
Total organic carbon	0.49	0.28	-0.59	-0.19
Suspended sediments				
Turbidity	-0.13	0.20	-0.61	0.19
Total suspended solids	-0.12	0.19	-0.40	0.04
Stream size				
Width	-0.16	0.42	-0.15	-0.23
Bankfull width	-0.02	0.38	-0.13	-0.28
Riparian cover				
Buffer height	-0.08	-0.06	0.17	0.00
Buffer width	-0.04	-0.19	0.59	-0.10
% Coniferous	-0.05	0.09	0.17	-0.16
% Deciduous	-0.07	-0.32	0.33	0.19
Center densiometer (mean)	-0.08	-0.05	0.20	-0.01
Bank densiometer (mean)	0.06	-0.11	0.31	-0.10
Solar pathfinder cover (mean)	0.06	-0.12	0.34	-0.10
Bedded sediments				
% Boulder		-0.04	-0.35	-0.29
% Cobble	-0.04		-0.33	-0.81
% Gravel	-0.35	-0.33		0.03
% Fines	-0.29	-0.81	0.03	